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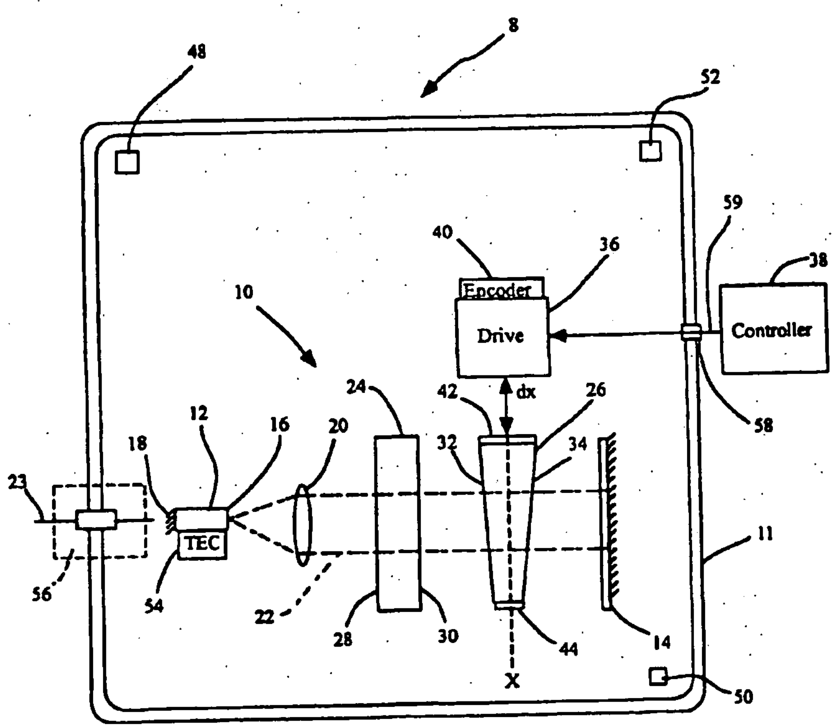
(54) Title: HERMETICALLY SEALED EXTERNAL CAVITY LASER SYSTEM AND METHOD



(57) Abstract: An external cavity laser in a hermetically sealed container and methods for hermetically sealing the external cavity laser. The external cavity laser may be tunable by various mechanisms to allow transmission at multiple selectable wavelength

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HERMETICALLY SEALED EXTERNAL CAVITY LASER SYSTEM AND METHOD

BACKGROUND OF THE INVENTION

Fiberoptic telecommunications are continually subject to demand for increased bandwidth. One way that bandwidth expansion has been accomplished is through dense wavelength division multiplexing (DWDM) wherein multiple separate data streams exist concurrently in a single optical fiber, with modulation of each data stream occurring on a different channel. Each data stream is modulated onto the output beam of a corresponding semiconductor transmitter laser operating at a specific channel wavelength, and the modulated outputs from the semiconductor lasers are combined onto a single fiber for transmission in their respective channels. The International Telecommunications Union (ITU) presently requires channel separations of approximately 0.4 nanometers, or about 50 GHz. This channel separation allows up to 128 channels to be carried by a single fiber within the bandwidth range of currently available fibers and fiber amplifiers. Improvements in fiber technology together with the ever-increasing demand for greater bandwidth will likely result in smaller channel separation in the future.

Transmitter lasers used in DWDM systems have typically been based on distributed feedback (DFB) lasers operating with a reference etalon associated in a feedback control loop, with the reference etalon defining the ITU wavelength grid. Statistical variation associated with the manufacture of individual DFB lasers results in a distribution of channel center wavelengths across the wavelength grid, and thus individual DFB transmitters are usable only for a single channel or a small number of adjacent channels. Continuously tunable external cavity lasers have been developed to overcome this problem.

The advent of continuously tunable telecommunication lasers has introduced additional complexity to telecommunication transmission systems. Particularly, the tuning aspects of such lasers involve multiple optical surfaces that are sensitive to contamination and degradation during use. Heretofore, no systems have been available which provide

components can have high outgassing characteristics during laser operation such that volatile hydrocarbons can contaminate and/or cause degradation of various optical surfaces of the external cavity laser. In this regard, the external cavity laser is configured to minimize or eliminate problems associated with outgassing by lubricants, adhesives, cable insulators and other components which contain volatile compounds and residual moisture by careful material selection and minimizing the use of potentially outgassing materials.

In certain embodiments, one or more activated carbon drains are sealed within the hermetically sealed enclosure and positioned to collect volatile hydrocarbons produced by outgassing from components of the external cavity laser. The activated carbon drain has a large surface area of activated carbon that allows for adsorbing or trapping the outgassing volatile organic compounds that occur during the operation of the laser. Organic hydrocarbon materials released from epoxies and lubricants used during the assembly of the external cavity laser of utilized in sealing the hermetically sealable enclosure are also trapped by the activated carbon drain. The activated carbon drain allows the optical surfaces of the tunable external cavity laser to remain free of organic contaminants in the hermetically sealed enclosure that would otherwise hinder performance.

In other embodiments, one or more moisture traps may be included within the hermetically sealable container and positioned to collect water vapor that may outgas from polyimide or other moisture holding insulator or material present in the external cavity laser. Such outgassed water vapor, if not trapped, may condense on critical optical surfaces and reduce performance of the external cavity laser, and may promote corrosion of components. Moisture condensation is particularly a concern after "cool-down" periods when the laser has not been in use. The material of the moisture trap may comprise a variety of desiccants. The moisture trap prevents condensation of water on optical surfaces and elsewhere that would otherwise reduce performance in the operation of the external cavity laser and promote corrosion of laser components within the hermetically sealed enclosure.

In one embodiment, the inert atmosphere sealed within the hermetically sealed container comprises nitrogen. Other inert gases may also be enclosed in the hermetically sealed enclosure such as helium, argon, krypton, xenon, or various mixtures thereof, including a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix. Helium may be added to the inert atmosphere to allow for testing and

BRIEF DESCRIPTIONS OF THE DRAWINGS

FIG. 1 is a schematic diagram of a hermetically sealed external cavity laser apparatus.

FIG. 2A-2C are graphical illustrations of pass band characteristics of the external cavity laser with respect to FIG. 1 for the wedge etalon channel selector, grid generator etalon, and external cavity with respect to a selected channel in a wavelength grid.

FIG. 3A-3C are graphical illustrations of gain response to tuning of the external cavity laser of FIG. 1 for a plurality of channels in a wavelength grid.

FIG. 4 is a perspective view of an external cavity laser in a hermetically sealable enclosure, shown with the cover removed.

FIG. 5 is a top plan view of the external cavity laser and hermetically sealable enclosure of FIG. 4, with the end mirror omitted.

FIG 6. is a schematic view of a laser sub-assembly of the hermetically sealable external cavity laser of FIG. 5.

FIG. 7 is a schematic view of the optical fiber feed through of the hermetically sealable external cavity laser of FIG. 5.

DETAILED DESCRIPTION

Referring more specifically to the drawings, for illustrative purposes the present invention is embodied in the apparatus and method shown in FIG. 1 through FIG. 7. It will be appreciated that the apparatus may vary as to configuration and as to details of the parts, and that the method may vary as to details and the order of events, without departing from the basic concepts as disclosed herein. The invention is disclosed primarily in terms of use with an external cavity laser.

rise to a multiplicity of minima within the communication band at wavelengths which coincide with the center wavelengths of a selected wavelength grid which may comprise, for example, the ITU (International Telecommunications Union) grid. Other wavelength grids may alternatively be selected. Grid etalon has a free spectral range (FSR) which corresponds to the spacing between the grid lines of the ITU grid, and the grid etalon 24 thus operates to provide a plurality of pass bands centered on each of the gridlines of the wavelength grid. Grid etalon 24 has a finesse (free spectral range divided by full width half maximum or FWHM) which suppresses neighboring modes of the external cavity laser between each channel of the wavelength grid.

Grid etalon 24 may be a parallel plate solid, liquid or gas spaced etalon, and may be tuned by precise dimensioning of the optical thickness between faces 28, 30 by thermal expansion and contraction via temperature control. The grid etalon 24 may alternatively be tuned by tilting to vary the optical thickness between faces 28, 30, or by application of an electric field to an electrooptic etalon material. Grid etalon 24 may be thermally controlled to prevent variation in the selected grid which may arise due to thermal fluctuation during operation of external cavity laser 10. Grid etalon 34 alternatively may be actively tuned during laser operation as described in the U.S. Patent Application Ser. No. 09/900,474 entitled “External Cavity Laser with Continuous Tuning of Grid Generator” to inventors Daiber et al., co-filed herewith, and incorporated herein by reference. Various other types of grid generator other than a grid etalon may be used with external cavity laser 10.

Wedge etalon 26 also acts as an interference filter, with non-parallel reflective faces 32, 34 providing tapered shape. Wedge etalon 26 may comprise, for example, a tapered transparent substrate, a tapered air gap between the reflective surfaces of adjacent transparent substrates, or a thin film "wedge interference filter. Wedge etalon 26 as shown in FIG. 1 is only one tunable element or channel selector which may be used in accordance with the invention in an external cavity laser. Wedge etalon 26 may be replaced with a variety of tunable elements other than an etalon, such as grating devices and electro-optic devices. The use of an air gap wedge etalon as a channel selector is described in U.S. Patent No. 6,108,355, wherein the “wedge” is a tapered air gap defined by adjacent substrates. The use of pivotally adjustable grating devices as channel selectors tuned by grating angle adjustment and the use of an electro-optic tunable channel selector in an external cavity laser and tuned by selective application of voltage are described in U.S. Patent Application Ser.

the wavelength grid. The combined feedback to gain medium 12 from the grid etalon 24 and wedge etalon 26 support lasing at the center wavelength of a selected channel. Across the tuning range, the free spectral range of the wedge etalon 26 is broader than that of grid etalon 24.

Wedge etalon 26 is positionally tuned via a tuning assembly which comprises a drive element 36 structured and configured to adjustably position wedge etalon 26 according to selected channels. Drive element 36 may comprise a stepper motor together with suitable hardware for precision translation of wedge etalon 26. Drive element may alternatively comprise various types of actuators, including, but not limited to, DC servomotors, solenoids, voice coil actuators, piezoelectric actuators, ultrasonic drivers, shape memory devices, and like linear actuators.

Drive element 36 is operatively coupled to a controller 38 which provides signals to control the positioning of wedge etalon 26 by drive element 36. Controller 38 may include a data processor and memory (not shown) wherein are stored lookup tables of positional information for wedge etalon 26 which correspond to selectable channel wavelengths. Controller 38 may be internal to driver element 36, or may be external and shared in other component positioning and servo functions of the external cavity laser 10. Controller as shown is external from hermetically sealed container 11, but may alternatively be internal to container 11.

When external cavity laser 10 is tuned to a different communication channel, controller 38 signals drive element 36 according to positional data in the look up table, and drive element 36 translates or drives wedge etalon 26 to the correct position wherein the optical thickness of the portion of the wedge etalon 26 positioned in optical path 22 provides constructive interference which supports the selected channel. A linear encoder 40 may be used in association with wedge etalon 26 and drive element 36 to ensure correct positioning of wedge etalon 26 by driver 36.

During tuning of wedge etalon26 , the length of the laser external cavity may also be tuned by positional adjustment of end mirror 14 using another tuning mechanism (not shown) which may comprise a DC servomotor, solenoid, voice coil actuator, piezoelectric actuator, ultrasonic driver, shape memory device, or other type of actuator. In certain

The laser apparatus 10 comprises at least one activated carbon drain 48 within hermetically sealed enclosure 11 for adsorbing or trapping volatile organics and hydrocarbons from outgassing of other components of external cavity laser 10 after sealing within enclosure 11. Activated carbon drain 48 has a large surface area of activated carbon configured to trap and retain volatile organic compounds which may be emitted from adhesives, lubricants, insulators or other organic material-containing components present within container 11 as described further below.

A moisture trap 50 is also provided within hermetically sealed container 11 to absorb moisture and prevent condensation of water vapor on the sensitive optical surfaces of the external cavity laser 10 after hermetically sealing within container 11. Water vapor may be emitted, for example from polyimide or other insulation material present in external cavity laser during operation within container 11. Moisture trap 50 may comprise a porous container of dried silica, calcium sulfate and/or other type of common dessicant.

The hermetically sealed enclosure 11 of the present invention may also comprise a sacrificial surface 52 on which both moisture condensation and volatile hydrocarbons from outgassing are trapped to avoid contamination of the optical services of the tunable external cavity laser 10. The sacrificial surface 52 may be cooled by an external cooling source and or be made of material or otherwise configured that can act as a heat sink which will selectively attract condensation of volatile organics and water vapor over surrounding or adjacent surfaces of higher temperature.

A heat source 54 may be used to heat gain medium 12 when gain medium 12 is not powered, in order to maintain an elevated temperature for the anti-reflective coating on the output facet 16 and prevent condensation thereon when external cavity laser 10 is not in use. As shown heat source 54 comprises a thermoelectric controller coupled to gain medium 12. Thermoelectric controller 54 may also be used during operation of gain medium 12 to thermally control the optical thickness across gain medium 12 between facets 16, 18. One or more additional heating elements (not shown) may be positioned internally or externally to the hermetically sealed enclosure 11 to maintain elevated temperatures for selected components to prevent condensation of contaminants thereon. Thus, heating may be used in connection with the end mirror 14 or channel selector 26 to maintain a temperature higher

The tuning of the band pass PB3 of wedge etalon 26 between a channel centered at 1549.5 nm and an adjacent channel at 1550 nm is illustrated graphically in FIG. 3A-3C, wherein the selection of a channel generated by grid etalon 24 and the attenuation of adjacent channels or modes is shown. The external cavity pass bands PB1 shown in FIG. 2A-2C are omitted from FIG. 3A-3C for clarity. The grid etalon 24 selects periodic longitudinal modes of the external cavity corresponding to the grid channel spacing while rejecting neighboring modes. The wedge etalon 26 selects a particular channel in the wavelength grid and rejects all other channels. The selected channel or lasing mode is stationary at one particular channel for filter offsets in the range of approximately plus or minus one half channel spacing. For larger channel offsets the lasing mode jumps to the next adjacent channel.

In FIG. 3A, the wedge etalon pass band PB3 is centered with respect to the grid channel at 1549.5 nm. The relative gain associated with pass band PB2 at 1549.5 nm is high, while the relative gain levels associated with adjacent pass bands PB2 at 1549.0 nm and 1550.0 nm are suppressed relative to the selected 1549.5 nm channel. The gain associated with pass bands PB2 at 1550.5 nm and 1548.5 nm is further suppressed. The dashed line indicates the relative gain for pass bands PB2 without suppression by wedge etalon 26.

FIG. 3B shows the wedge etalon pass band PB at a position in between the channels at 1549.5 nm and 1550.0 nm, as occurs during channel switching. The relative gain associated with pass bands PB2 at 1549.5 nm and 1550.0 are both high, with neither channel suppressed. The relative gain levels associated with pass bands PB2 at 1549.0 nm and 1550.5 nm are suppressed relative to the 1549.5 nm and 1550.0 nm channels. The dashed line indicates the relative gain for pass bands PB2 without suppression by wedge etalon 26.

FIG. 3C shows the wedge etalon pass band PB3 centered with respect to the grid channel at 1550.0 nm, with the relative gain associated with the pass band PB2 at 1550.0 nm being high, while the relative gain levels associated with adjacent pass bands PB2 at 1549.5 nm and 1550.5 nm are suppressed relative to the selected 1550.0 nm channel, and the gain associated with pass bands PB2 at 1551.0 nm and 1549.0 nm is further suppressed. Again, the dashed line indicates the relative gain for pass bands PB2 without suppression by wedge etalon 26.

transformer 80 is supported on ceramic board 82 to provide power to a phase modulator 83 (FIG. 4) coupled to the laser end mirror (not shown). Linear encoder 40 is mounted to container 11 adjacent an encoder scale 84 and is used to monitor the positioning of wedge etalon 26. A photodetector 85 (FIG. 4) is positioned in the laser optical path behind phase modulator 83 and is used to monitor laser performance.

Encoder 84 and transformer 80, like stepper motor 62, are engineered and configured for minimal outgassing within hermetic container 11 during laser operation. In this regard, insulator materials in encoder 84 and transformer 80, as well as elsewhere within hermetic container are minimized and are selected for low outgassing characteristics.

Holes 86 (FIG. 4) are provided in container 11 to allow hermetic sealing of electrical leads 59 extending therethrough by use of electric feedthroughs 58 (FIG. 1). Feedthroughs 58 comprise glass sleeves that fit into holes 86 and through which leads 59 fit. Feedthroughs 58 and leads 59 are hermetically fused into holes 86 by exposure to elevated temperature. The hermetic sealing of leads in this manner is carried out prior to inclusion of any heat sensitive components within container 11.

The hermetically sealable enclosure 11 is metal plated to prevent rust or corrosion from arising after sealing the external cavity laser 61 within enclosure 11. The hermetically sealed enclosure 11 may be made of KOVAR® Ni-Fe-Co alloy or other metal or metal alloy having good corrosion resistance and formability suitable for hermetic enclosures. Hermetic enclosure 11 is plated with gold or other corrosion-resistant metal or metal alloy to provide clean, corrosion-resistant surfaces. The enclosure 11 is metal plated under conditions that safeguard against possible contamination, such as class 100 or higher clean room conditions. Where possible, the use of adhesives is avoided within hermetic container 11 and fluxless solders are utilized for bonding. Circuit boards 88, 82 and 78 are made of ceramic instead of fiberglass-reinforced resin (to avoid outgassing associated with resin-containing boards), and are attached directly to the container 11 by a fluxless solder process. Lid 89 (only a portion of the lid is shown in FIG. 5) conforms generally to the shape of container 11, and includes a Ni-Au plating to allow for hermetic sealing to container 11 to form a hermetically sealed enclosure about the laser apparatus 61 therewithin.

Hermetic sealing is provided in association with optical fiber 23 by fiber feedthrough assembly 56, which is shown schematically in FIG. 7. The fiber feedthrough 56 is configured to hermetically seal the optical fiber 23. The outer 110 jacket and inner jacket 112 of the optical fiber 23 are removed from the portion of the fiber 23 which extends into enclosure 11 to avoid outgassing from the insulation material of the inner 112 and outer 110 jackets. A ferrule 114 extends through the wall of container 11, with fiber 23 extending through ferrule 114. On the inner side 115 of container 11, fiber 23 (from which jackets 110, 112 have been removed) is hermetically fused in place by a solder plug 116. The optical fiber 23 and inner surface of ferrule 114 may be metallized to facilitate soldering. An expoxy plug 117 holds fiber 23 in place adjacent the outer side 118 of container 11. The fiber feedthrough 56 is configured to provide pull stress support to fiber to prevent damage from handling.

In the fabrication of the hermetically sealed external cavity laser apparatus 61, the use of lubricants, adhesives, cable insulators and other materials which contain volatile compounds and residual moisture is minimized to limit material outgassing. Elements of the hermetically sealed laser 61 which are the most prone to outgassing include stepper motor 62, encoder 40, and transformer 80, and material selection to avoid outgassing is carried out where possible. Preparation and assembly of the various components of the apparatus 61 may be carried out under clean room conditions, and one or more cycles of vacuum baking, and/or or baking under inert atmosphere may be carried out to remove residual moisture and volatile organic hydrocarbons from the various components prior to hermetically sealing the enclosure 61 around the external cavity laser. In particular, one or more cycles of vacuum baking, followed by purging with inert atmosphere, may be carried out on the entire assembly for the apparatus 61, including the hermetically sealable lid 89.

Following the final vacuum baking/inert atmosphere purge cycle, the lid is hermetically sealed onto the enclosure in the presence of an inert, moisture-controlled atmosphere such that all components within the enclosure are hermetically sealed within. Moisture control provides a dry inert gas for container 11, and ensures minimal inclusion of moisture within container 11 after sealing. Numerous methods for hermetically sealing lids to containers are known in the art and may be used. The inert atmosphere used for hermetic

CLAIMS

That which is claimed is:

1. A laser apparatus comprising an external cavity laser, and a hermetically sealable container configured to enclose said external cavity laser in an inert atmosphere.

2. The apparatus of claim 1, wherein said inert atmosphere is moisture controlled.

3. The apparatus of claim 1, wherein said external cavity laser is tunable.

4. The apparatus of claim 3, wherein said external cavity laser comprises a gain medium having a first and second output facets, said second output facet having anti-reflective coating thereon.

5. The apparatus of claim 4, wherein said external cavity laser further comprises an end mirror, said end mirror and said first output facet of said gain medium defining an external cavity, said gain medium emitting a beam from said second output facet along an output path.

6. The apparatus of claim 5, further comprises a tuning assembly operatively coupled to said end mirror and configured to adjust said end mirror, in said hermetically sealable container.

7. The apparatus of claim 3, wherein said external cavity laser comprises a grid generator.

8. The apparatus of claim 1, wherein said external cavity laser comprises a channel selector.

9. The apparatus of claim 8, comprising a tuning assembly operatively coupled to said channel selector and configured to adjust said channel selector.

18. The apparatus of claim 17, further comprising a tuning assembly operatively coupled to said channel selector and configured to adjust said channel selector, said tuning assembly positioned within said hermetically sealed container.

19. The apparatus of claim 14, further comprising an activated carbon drain positioned within said hermetically sealed container.

20. The apparatus of claim 14, further comprising a moisture trap positioned within said hermetically sealed container.

21. The apparatus of claim 14, wherein said inert atmosphere is a gas selected from nitrogen, helium, neon, argon, krypton, xenon, a nitrogen-helium mix, a neon-helium mix, a krypton-helium mix, or a xenon-helium mix.

22. A method for fabricating a laser, comprising:

(a) providing an external cavity laser; and

(b) hermetically sealing said external cavity laser in an inert atmosphere within a hermetically sealed container.

23. The method of claim 22, wherein said external cavity laser comprises a gain medium having an anti-reflective surface thereon, and an end mirror positioned in an optical path defined by a beam emitted from said gain medium.

24. The method of claim 23, wherein said external cavity laser comprises a tuning assembly operatively coupled to said end mirror and configured to adjust said end mirror.

25. The method of claim 22, wherein said external cavity laser comprises a grid generator.

26. The method of claim 22, wherein said external cavity laser comprises a channel selector.

37. The apparatus of claim 36, wherein said external cavity laser and said tuning means are enclosed within said hermetically sealing means.

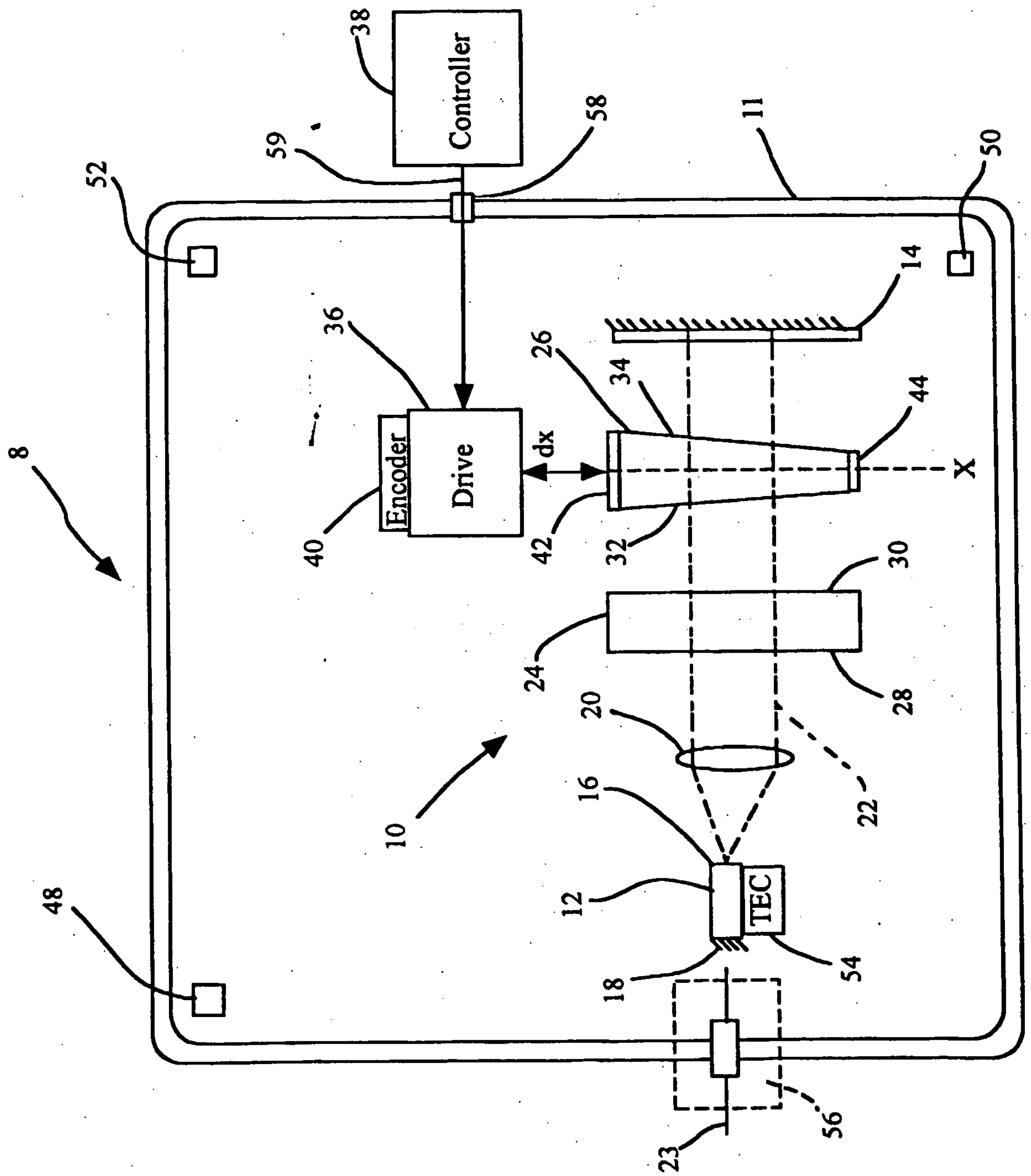
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Fig. 1

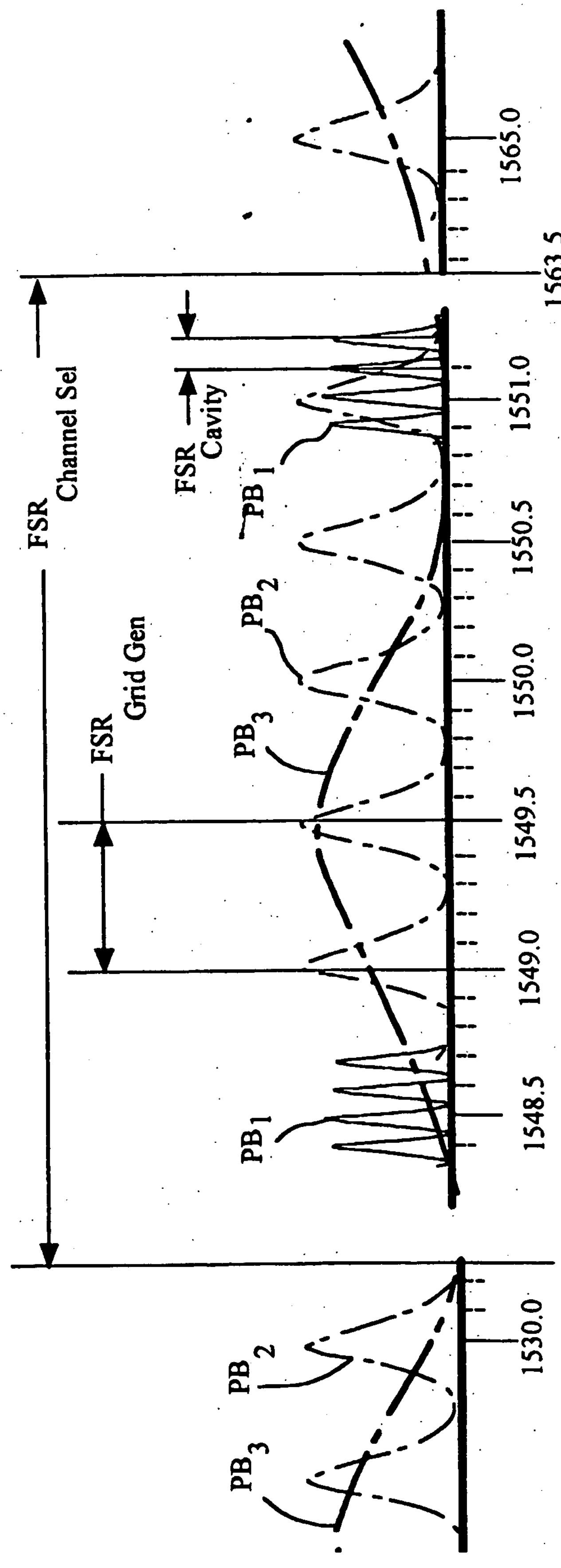


Fig. 2A

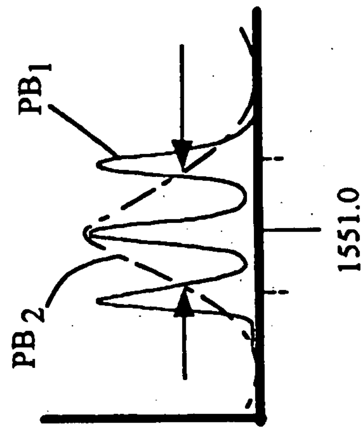


Fig. 2B

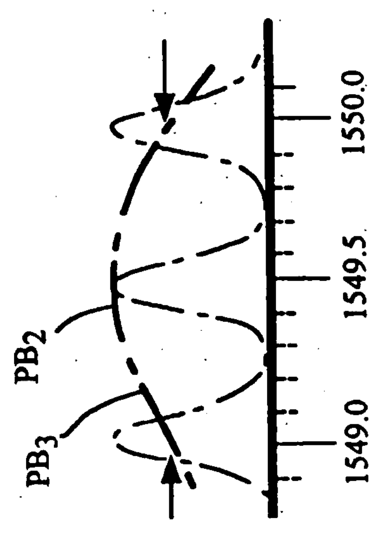


Fig. 2C

Fig. 3A

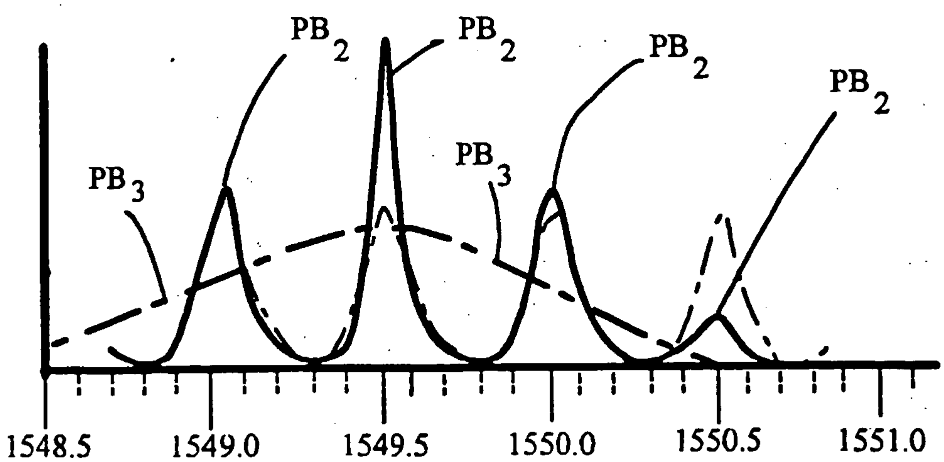


Fig. 3B

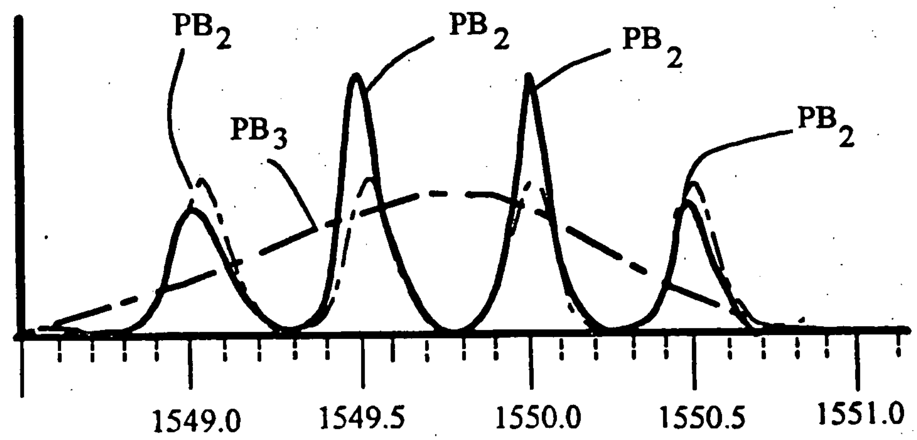
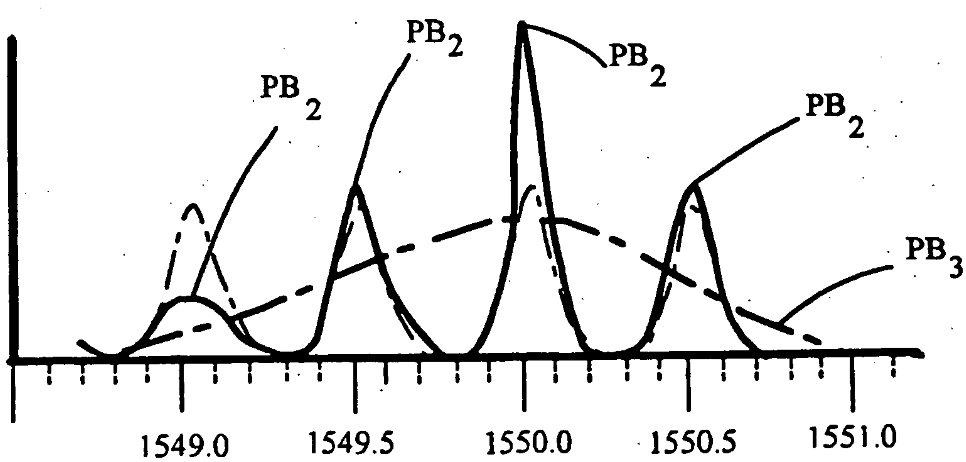


Fig. 3C



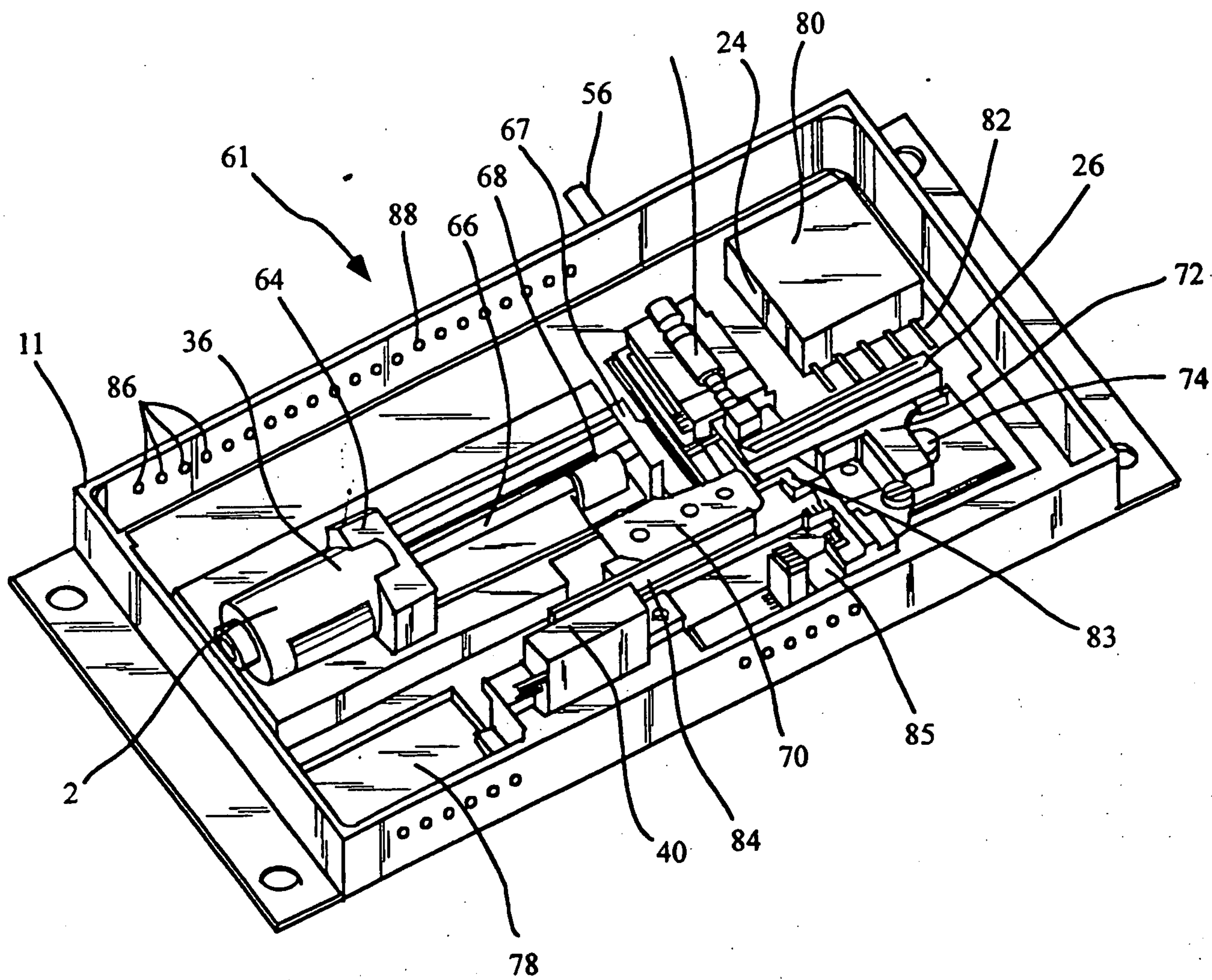


Fig.4

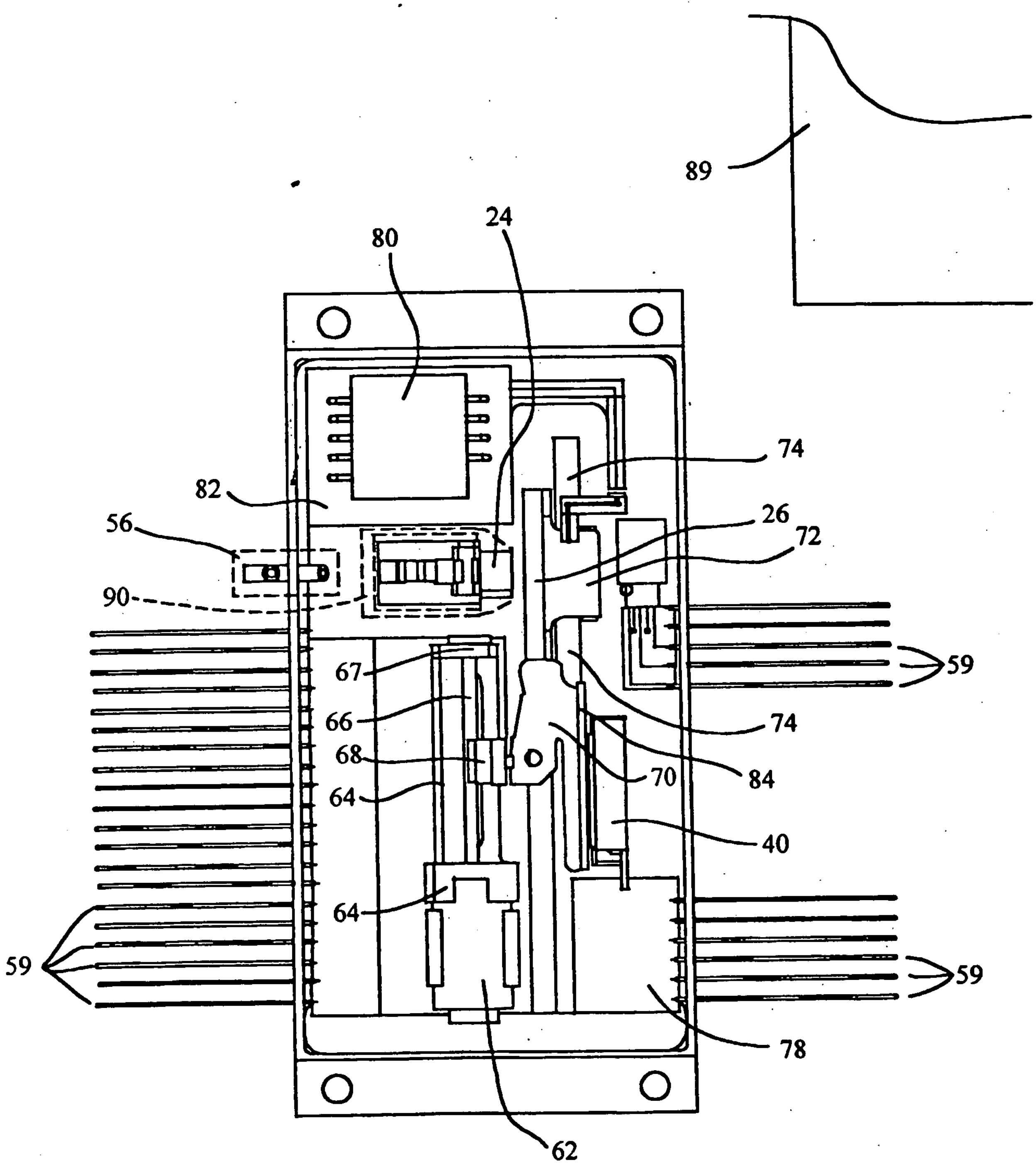


Fig.5

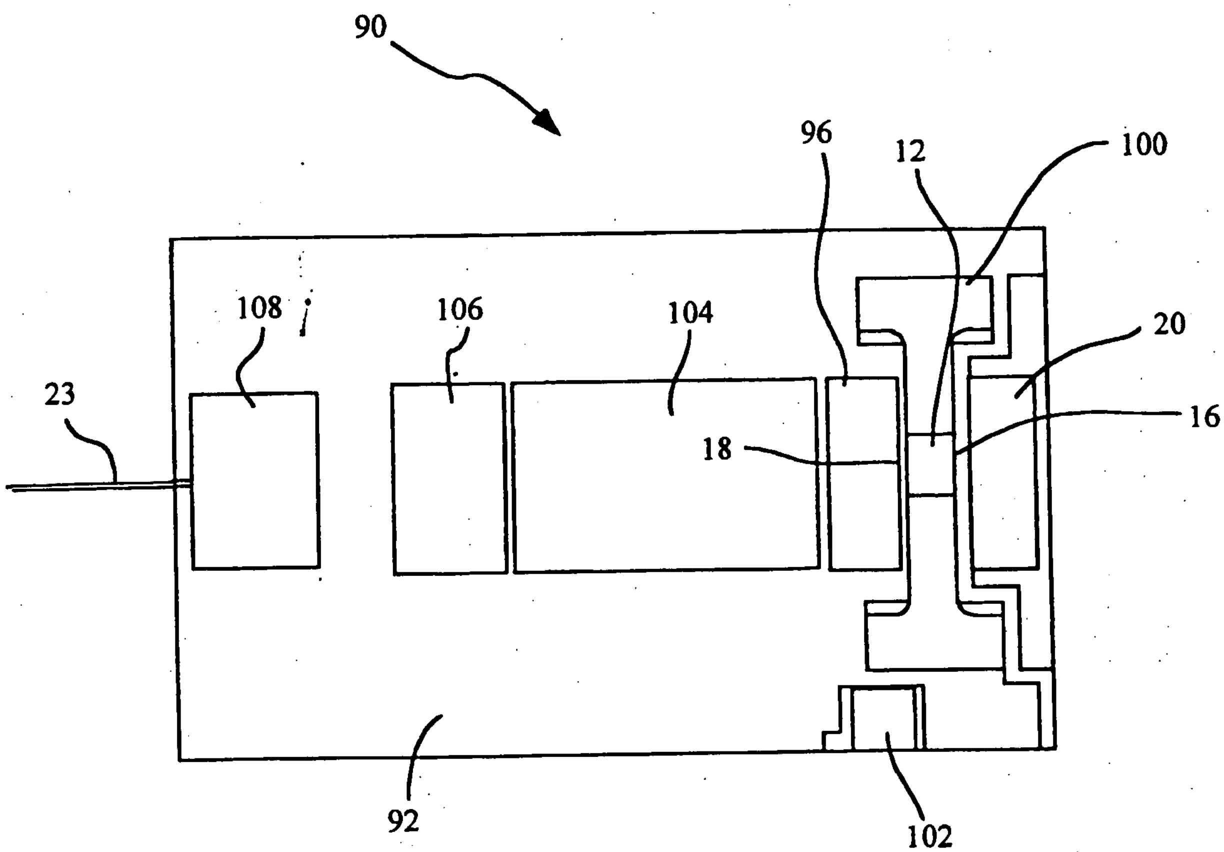


Fig. 6

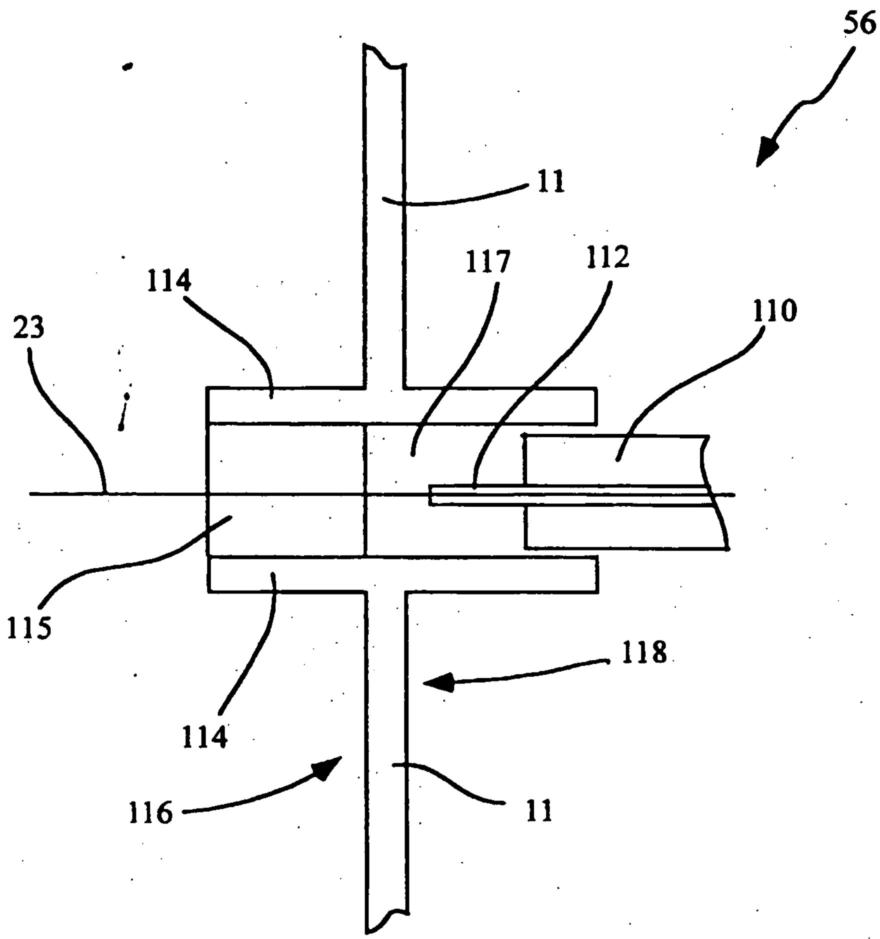


Fig. 7